International Institute of Tropical Agriculture (IITA)

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Postharvest physiology of plantain and banana

Objectives. This guide is intended to enable you to:

- describe the objectives of postharvest research
- discuss the physiological development of plantain and banana fruits
- explain transpiration and respiration of fruits
- analyze factors affecting ripening

Study materials

- Production and consumption statistics.
- Samples of plantain and banana cultivars.
- Samples of plantain and banana at different development stages and conditions.
- Equipment to measure respiration rate and other fruit characteristics.

Practicals

- Identify quality parameters and requirements important to farmers, retailers, and consumers.
- Determine stages of physiological development of plantain and banana samples.
- Measure the respiration rate of fruits in different development stages and conditions.

Questions

1 How did plantain and banana cultivars develop?
2 To what farming systems are plantain and banana particularly suited?
3 Why is postharvest research particularly important for plantain and banana?
4 What are the most important metabolic processes before and after harvest?
5 What quality parameters are important to farmers, retailers, and consumers?
6 What are the 4 stages of physiological development of plantain and banana fruits?
7 What is the effect of ripening?
8 What major biochemical changes occur during ripening?
9 What are 'catabolic' processes?
10 What typical changes happen during the ripening of pineapple fruits?
11 How can you extend market life and improve overall fruit quality?
12 To what factors is transpiration rate related?
13 What important result does respiration produce?
14 Why can plant products harvested at a mature stage be stored longer than products harvested at an early growth stage?
15 How is the rate of respiration related to storage life?
16 How can you measure the respiration rate?
17 What is the 'climacteric respiratory response'?
18 What factors affect plantain and banana ripening?
19 What is the optimum storage temperature for plantain and banana?
20 What is the relationship between fruit weight (water) loss and ripening period?
21 What is 'green life'?

Postharvest physiology of plantain and banana

Abstract. Postharvest research is concerned with maintaining crop quality until the crop reaches the consumer. Postharvest physiology includes study of the physiological development of fruits, and their metabolic processes, especially transpiration and respiration. Postharvest improvements aim to slow down these processes, to extend storage life, and improve fruit quality.

1 Postharvest research

Plantain and banana (*Musa* spp.) are giant perennial herbs that originated in Southeast Asia. Plantain and banana cultivars evolved by natural hybridization between the two species *M. acuminata* (contributing genome A) and *M. balbisiana* (contributing genome B). All important plantains and bananas are triploid. Plantain and banana are monocotyledonous plants belonging to the section Eumusa within the genus *Musa* of the family Musaceae in the order Scitamineae.

Plantain and banana are important food crops in the humid forest and mid-altitude agroecologies of sub-Saharan Africa. They provide more than 25% of the carbohydates for 70 million people. The area between the lowlands of Guinea and Liberia in West Africa, and the central basin of Democratic Republic of Congo in Central Africa produces more than 50% of the plantain in the world. In the East African highlands, plantain and banana are a staple crop, and the region records the highest consumption figures in the world. Plantain and banana are high yielding and particularly suited to the farming systems in sub-Saharan agroecologies.

Farming includes all crop-related activities from planting until the harvested product is either sold or eaten. Preharvest crop management of plantain and banana has a direct effect on postharvest characteristics. A high quality crop gives the best postharvest performance.

Postharvest research is concerned with maintaining crop quality until the crop reaches the consumer. This research is particularly important for perishable crops which deteriorate rapidly, such as plantain and banana.

Postharvest deterioration of plantain and banana fruits is due to metabolic processes. Harvested plantain and banana remain 'living', and continue the same metabolic reactions as when attached to the plant. However, harvested fruits must use their own resources in these metabolic processes. Transpiration and respiration are the most important metabolic processes before and after harvest. Postharvest physiology includes the study of these metabolic processes.

Postharvest studies also identify quality parameters that are important to farmers, retailers, and consumers, and determine how environmental factors affect postharvest quality. Important postharvest parameters for plantain and banana include cultivar, optimum fruit maturity at harvest, fruit size, ripening period, peel color, pulp color, texture, pH, dry matter content, and sugar content. Environmental factors which affect postharvest quality of plantain and banana include temperature, humidity, light intensity, and air composition within a storage area.

2 Physiological development of fruits

Physiological development of plantain and banana fruits includes 4 stages:

- growth
- maturation
- ripening
- senescence

These stages are arbitrary, that is, they are invented for purposes of research. Strict physical or biochemical definitions are difficult to apply to all fruits. Fruits do not have identical types and/or rates of development, but researchers make general assumptions.

Growth. Growth involves cell division and cell expansion, which accounts for the final size of the fruit.

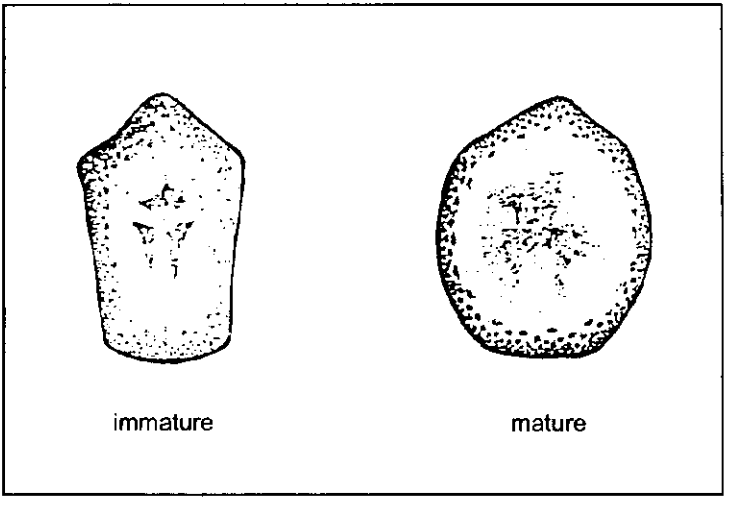
Maturation. Maturation usually starts before growth stops. Immature plantain and banana fruits are angular, with sharp edges and well-pronounced ridges. As plantain and banana mature, the fruits become more rounded (Figure 1). Further changes include coloration from green to yellow and the development of attractive flavors and aromas.

Growth, maturation, and senescence occur in all crops, but for fruits, including plantain and banana, another process termed 'ripening' also plays a part.

Ripening. Ripening is a biochemical process occurring in fruit between late maturation and early senescence. Ripening transforms a physiologically mature but often inedible plant into a visually attractive fruit with characteristic aromas and flavors.

Ripening also makes the fruit more attractive to animals as agents of seed dispersal. Plantain is unusual because it is consumed at all stages of maturity and ripeness.

Figure 1. Cross-sections of immature and mature plantain/banana fruits.



Major biochemical changes occurring during ripening are:

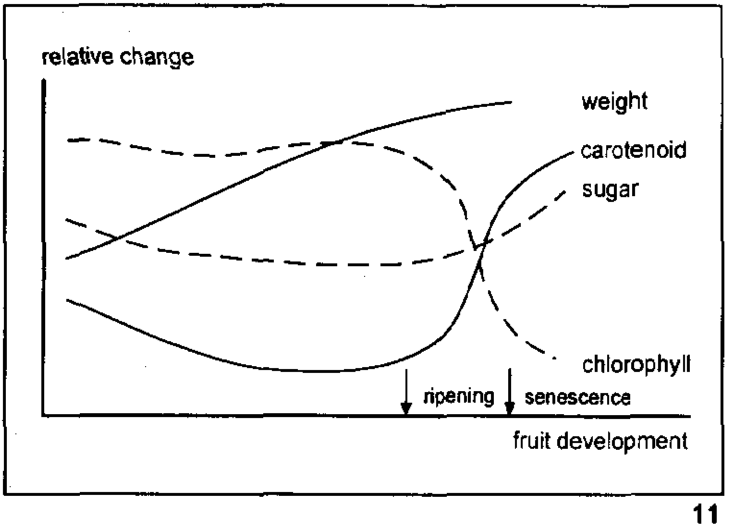
- seed maturation (in pollinated fruits)
- peel color change
- abscission (detachment of fruits from parent plant)
- a dramatic rise in respiration rate
- increased ethylene production
- increased peel permeability
- softening of pulp tissue
- decrease in starch:sugar ratio
- production of volatiles (flavor and smell)

Senescence. During senescence, catabolic (degenerative/breaking down) biochemical processes replace anabolic (synthetic/building up) processes. This causes aging and finally death. In plantain and banana, the most obvious changes relating to fruit senescence are peel color change, from yellow to black, and softening pulp.

Pineapple illustrates typical changes during fruit ripening and provides a comparison with plantain and banana ripening (Figure 2). Weight increases during growth, stabilizes at the onset of ripening, and falls during senescence. Chlorophyll levels in fruit peel decrease on ripening. Levels of carotenoid (the yellow pigment found in ripe fruits) increase. Sugar levels increase during senescence.

Fruit growth and maturation can only be completed when the fruit is attached to the plant. Ripening and senescence occur whether the fruit is attached or detached from the plant. Fruit is generally harvested either when mature, at full size, or when ripe, having developed full flavor and color.

Figure 2. Development of pineapple fruits.



3 Transpiration and respiration

The most important physiological processes in harvested plantain and banana fruits are:

- transpiration
- respiration

Postharvest improvements aim to slow down these physiological processes. A reduction in the rate of transpiration or respiration extends market life and improves overall fruit quality.

Transpiration. Plants lose water by transpiration through the stomata. Transpiration is related to cooling and photosynthesis. As temperature increases, the rate of transpiration also increases.

Fruits lose water through the peel. Different fruits lose water at different rates, because of varying peel thickness. An orange, for example, has a thick waxy peel which holds in water, whereas a grape has a very thin peel which increases water loss. Plantain and banana are intermediate between these two crops.

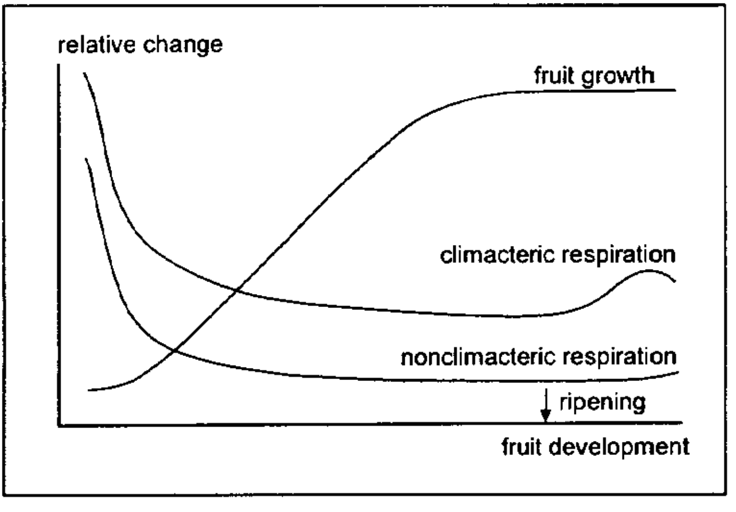
Respiration. Respiration involves the uptake of oxygen, the release of carbon dioxide, and the breakdown of stored reserves. Respiration provides energy for metabolism, growth, and maturation. All cells respire, continuously oxidizing starch and sugars to produce carbon dioxide, water, and energy.

Respiration is described by the equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy}$$

Respiration rate indicates metabolic activity in plant tissue. It is also a guide to the potential storage life of fruits. Generally, the higher the respiration rate, the shorter the storage life. Respiration rate is measured by recording carbon dioxide production. Generally, respiration rate is highest at the early growth stage, and declines with fruit maturity (Figure 3). However, plantain and banana are exceptions because of the climacteric response.

Figure 3. Respiration rate during fruit development.



Crops harvested at an early growth stage have a high respiration rate and a short storage life. For example, young, rapidly growing lettuce leaves or banana flowers, which are eaten in Southeast Asia, are harvested at an early growth stage. Such products have a storage life of 1–2 days at ambient tropical temperatures. Plant products harvested at a mature stage, for example, potatoes and watermelons, can be stored for several weeks with little change in quality. For this reason, fruits are usually harvested at a late stage of maturity.

Climacteric response. Initially, plantain and banana show a gradual decrease in respiration with maturity. Then, pulp tissue suddenly produces a large amount of ethylene. The high concentration of ethylene triggers a rapid increase in respiration, which is termed the 'climacteric response' (Figure 3). At this point, all characteristic changes of ripening occur.

Fruits like plantain, banana, tomato, mango, and papaya have a climacteric respiratory pattern and are called climacteric fruits. Table 1 lists examples of climacteric and nonclimacteric fruits.

Climacteric fruits are identified by three major events:

- a rapid burst in ethylene production
- a sharp rise in respiration, indicated by an increase in carbon dioxide production
- a decrease in the oxygen level of internal tissues (pulp)

The climacteric response and full ripening occur whether the fruit is still attached to the parent plant or harvested. Ripening is slower in nonclimacteric fruits than in climacteric fruits. The division of fruits into climacteric and nonclimacteric is important, as it affects handling and storage.

The climacteric respiratory response has been the subject of much research. However, the control mechanism for this process is still unclear. Ethylene is an important agent in ripening and may have a moderating/coordinating role.

Table 1. Climacteric and nonclimacteric fruits.

Climacteric	**Nonclimacteric**
Plantain	Pineapple
Cooking banana	Lemon
Dessert banana	Orange
Avocado	Cucumber
Kiwi fruit	Grape
Mango	Orange
Papaya	
Passion fruit	
Tomato	
Watermelon	

4 Factors affecting ripening

Factors affecting plantain and banana ripening can be physiological, physical, or biotic.

Physiological factors relate to fruit maturity or environmental factors, which affect the metabolism of plantain and banana.

Physical factors include mechanical damage, or relate to dimensions of the fruit.

Biotic factors include attack from pests and diseases.

Fruit maturity. The more mature plantain is at harvest, the shorter the ripening period. Studies show that False Horn plantain harvested 100 days after flowering ripened in 11 days. When the same cultivar was harvested 90 days after flowering, the ripening period increased to 15 days, and further increased to 22 days when the fruit was harvested at 80 days. Farmers have to match the date of harvest with the transportation time to the market. However, an early harvest reduces yield.

As fruits mature, the cross-sectional diameter increases. Fruit angularity also changes during growth and maturation. As fruits approach full maturity, fruit angles become less acute (Figure 1). Fruit angularity can be used to predict the optimum harvest date.

Temperature. Physiological studies on bananas show that storage life decreases as external temperature increases over the range 15–35°C. A 1°C reduction increases storage period by 1–2 days.

However, at temperatures below 11°C, fruits suffer chilling injury. Therefore, optimum storage temperature for plantain and banana fruits is 13–14°C. This temperature will maintain fully mature, ripe and unripe fruits for 1–2 weeks. Storage period can extend to 4 weeks when plantain and banana are harvested up to 4 weeks before full maturity.

The relationship between ripening period and temperature is due to fruit respiration. Fruit respiration depends on many enzymatic reactions, and the rate of these reactions increases exponentially with increase in temperature. Studies show that ripe fruits respire at approximately 4 times the rate of unripe fruits. Consequently, ripe fruits lose sugar resources at a higher rate than unripe fruits. This explains why ripe fruits deteriorate quickly.

The relationship between temperature and respiration is described mathematically by van't Hoff's temperature quotient (Q_{10}). van't Hoff showed that the rate of respiration approximately doubles for each 10°C rise in temperature.

Water loss and humidity. Where fruit is sold on a weight basis, loss of water means economic loss. Additionally, water loss reduces visual quality. Water loss causes plantain to lose its firmness, the peel becomes soft and shriveled, and ripening period reduces.

Detailed studies on plantain show a curvilinear or power relationship between fruit weight loss and ripening period (Figure 4). For a 2% change from 2% to 4% weight loss per day, ripening period reduced by 9 days or 50%. However, for the same 2% change from 8% to 10% per day, only a 1 day or 5% reduction in the ripening period occurred. Therefore, at a low rate of weight loss, a small increase in weight loss has a critical effect on ripening.

The rate of water loss depends on the ambient relative humidity (RH). RH is the amount of water vapor present in the air, relative to the maximum amount of water vapor that can be held in the air, at a given temperature, saturated air being 100% RH. When a water-containing material such as fruit is placed in an enclosed space, for example, a sealed container, the water content of the air within the container increases or decreases until it is in equilibrium with the fruit.

The water equilibrium principle applies when fruit is stored. The rate of water loss depends on the ambient RH. At an ambient RH of 95–100%, fruit loses little or no moisture, and ripening period is unaffected. However, as humidity decreases, the rate of water loss increases, and ripening period reduces.

Excessive wetting can also be a problem. When plantain is stored in wet conditions, such as in moist coir (coconut fiber), the uptake of water from the coir to the plantain leads to peel splitting.

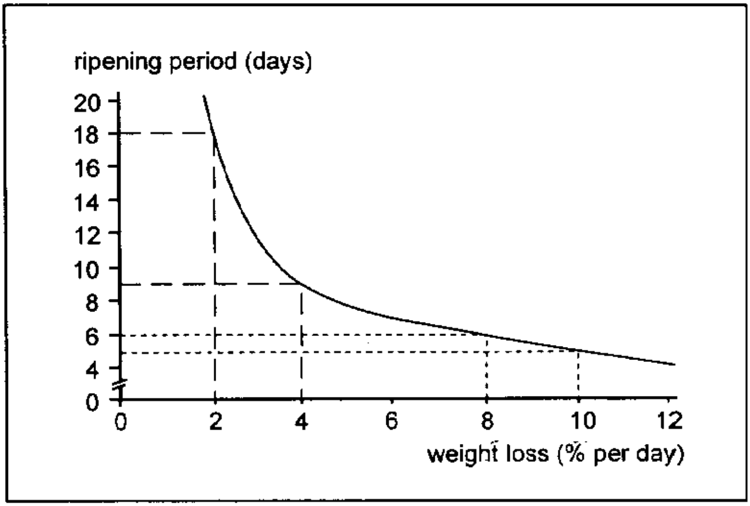


Figure 4. Fruit weight loss during ripening period.

Sunlight. Exposure to direct sunlight reduces the ripening period of plantain and banana. Sunlight increases fruit temperature above ambient temperature, which increases respiration, and possibly the rate of water loss. Therefore, in traditional African markets, some traders shade their produce.

Ethylene. Ethylene (C_2H_4) is a gaseous plant hormone which determines the time between harvest and senescence. The time from harvest to the climacteric respiratory response is called the 'green life' or preclimacteric period. Ethylene shortens the preclimacteric period; at high concentrations, ethylene causes rapid initiation of the climacteric respiratory response and accelerates ripening.

All fruits produce small amounts of ethylene during development and when damaged or stressed. During ripening, climacteric fruits produce larger amounts of ethylene than nonclimacteric fruits.

When ethylene is applied to climacteric fruits, at a concentration as low as 0.1–1.0 μl/l, for 1 day, ripening starts. Once ripening starts, climacteric fruits ripen within 1–2 days.

When nonclimacteric fruits are exposed to ethylene, fruits show an increased rate of respiration. However, respiration rate falls when ethylene is removed. A rise in respiration rate may occur more than once in nonclimacteric fruits. However, for climacteric fruits, the climacteric is autocatalytic, that is, once started, the process cannot be stopped until the fruit is ripe.

Poor storage methods allow a build up of ethylene, stimulate the climacteric response, and reduce the ripening period. For example, plastic sheets placed over stacks of fruit for shade increase the level of ethylene within the plantain stack and increase the rate of ripening. Therefore, store plantain in thatched or ventilated areas to prevent the build up of ethylene. Also, do not store unripe fruits with ripe fruits.

*During the preclimacteric period, fruits are less suscepti*ble to physical damage and pathological attack. This is the best time for handling, transportation, and marketing.

Mechanical damage. Mechanical damage is a physical factor affecting ripening. Fruit damage during handling generates ethylene. If ethylene production is sufficient to start the climacteric respiratory response, fruit imme diately starts to ripen.

Damage can also reduce ripening period by causing moisture loss. The effect of damage can easily be measured by recording fruit weight loss over time. Cuts and abrasions on the surface membrane cause the most weight loss.

After harvest, fruits lose the ability to repair ruptured peel. Harvesting techniques which damage fruit reduce storability.

Studies on plantain show that an abrasion affecting 5–10% of the peel can reduce the ripening period by 40%. A trader selling abraded fruit has half the normal time to sell an already less attractive product. Damage can also lead to secondary infection, which increases the rate of water loss and further reduces quality.

Surface to volume ratio. The ratio between surface area and volume determines the rate of water loss. The greater the surface to volume ratio, the shorter the postharvest life. A leaf which has two large surfaces with little volume loses moisture faster than a fruit. Large fruits lose less water than small fruits.

Peel thickness. Fruits with thin peel lose more water. A higher peel permeability leads to a higher rate of water loss and a faster ripening rate. Also, fruits with thick peel, for example melons, withstand damage better than fruits with thin peel, such as tomatoes.

Stomatal density. A higher density of stomata may cause a higher rate of water loss, which accelerates ripening. Studies show that the French plantain cultivar Obino l'Ewai has a more dense arrangement of stomata than other cultivars.

Biotic stress. Fungi, bacteria, viruses, and insects also account for a considerable proportion of total postharvest loss. Pests and diseases reduce both ripening period and overall quality. However, attack by pests and diseases is often secondary because a pest exploits a damaged area of the fruit. Careful fruit handling often prevents such attacks.

5 Bibliography

Brady CJ. 1987. Fruit ripening. In: Davies DD (ed.). The Biochemistry of Plants, Vol. 12, pages 155–178. Academic Press, London, UK.

Ferris RSB. 1997. Improving storage life of plantain and banana. IITA Research Guide 62. Training Program, IITA, Ibadan, Nigeria. 22 pages.

Ferris RSB. 1998. Postharvest evaluation of plantain quality. IITA Research Guide 63. Training Program, IITA, Ibadan, Nigeria.

Ferris RSB. 1998. Nutrition, utilization, and processing of plantain and banana. IITA Research Guide 65. Training Program, IITA, Ibadan, Nigeria.

Ferris RSB, Hotsonyame GK, Wainwright H, Thompson AK. 1993. The effect of genotype, damage, maturity and environmental conditions on the postharvest life of plantain. Tropical Agriculture (Trinidad) 70: 45–50.

Littmann MD. 1972. The effect of water loss on the ripening of climacteric fruits. Queensland Journal of Agriculture and Animal Science 29: 115–130.

Rhoades RE. 1996. The art of the informal agricultural survey. IITA Research Guide 36. Training Program, IITA, Ibadan, Nigeria. 57 pages.

Seymour GB. 1992. Banana. In: Tucker G, Seymour GB. (eds), Biochemistry of Fruits and their Products. Chapman and Hall, London, UK.

Simmonds NW (ed.). 1966. Bananas. Longman, Green and Co., London, UK. 512 pages.

Swennen R, Ortiz R. 1997. Morphology and growth of plantain and banana. IITA Research Guide 66. Training Program, IITA, Ibadan, Nigeria. 32 pages

Tindall HD, Proctor FJ. 1980. Loss prevention of horticultural crops in the tropics. Progress in Food Nutrition Science 4: 25–39.

Wills RBH, McGlasson WB, Graham D, Lee TH, Hall EG. 1989. Physiology and biochemistry of fruit and vegetables. In: Wills RBH, McGlasson WB, Graham D, Lee TH, Hall EG (eds.), Postharvest, pages 17–39. Blackwell Scientific Publications, Oxford, UK. 174 pages.

6 Suggestions for trainers

If you use this Research Guide in training ...

Generally:

- Distribute handouts (including this Research Guide) to trainees one or several days before your training activity, or distribute them at the end of your presentation.

- Do not distribute handouts at the beginning of a presentation, otherwise trainees will read instead of listening to you.

- Ask trainees not to take notes, but to pay full attention to the training activity. Assure them that your handouts (or this Research Guide) contain all relevant information.

- Keep your training activities practical. Reduce theory to the minimum that is necessary to follow the practical exercises.

- Use the questionnaire on page 4 (or a selection of questions) for examinations (quizzes, periodical tests, etc.). Allow consultation of handouts and books during examinations.

- Promote interaction of trainees. Allow questions, but do not deviate from the subject.

- Control your time.

Specifically:

- Discuss with trainees about experiences and problems of postharvest physiology (10 minutes).

- Present and discuss the content of this Research Guide, using the study materials listed on page 3 (1½ hours).

  Have samples of plantain and banana fruits available for each trainee.

  You may photocopy the illustrations of the Research Guide on transparencies for projection with an overhead projector.

- Conduct the practicals suggested on page 3 in groups of 3–4 trainees per group (1½ hours). Make sure that each trainee has the opportunity to practice. Have resource persons available for each group and practical.

  Organize your practicals and demonstrations well. Keep trainees busy.

- Organize informal surveys at farms and markets to identify quality parameters and requirements important to farmers, retailers, and consumers (½ day; see Rhoades 1996). Assign groups of trainees different places or tasks. Summarize and discuss the findings of the groups (1½ hours).

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